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ABSTRACT

The U. S. Environmental Protection Agency's (EPA) Air and Energy Engineering Research Laboratory (AEERL) has developed a research plan for their work in the global climate area. The plan has been written for discussion with senior scientists and program managers at the EPA's Global Climate Change Research Program Workshop to be held in September 1987. The AEERL's program consists of five major parts: emission inventory, emission factor development, emission forecast model, control technology assessment, and control technology development. Plans for work in each of these areas and the relationship of AEERL's work to work being done by other researchers are discussed in the research plan. Projected budgets and schedules are presented.

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AEERL RESEARCH PLAN ON THE GLOBAL CLIMATE EMISSIONS ASSESSMENT AND STABILIZATION PROGRAM

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1.0 INTRODUCTION

The EPA is one of several agencies and organizations playing a major role in the U. S. National Climate Program established by the National Climate Program Act. Areas of emphasis defined for EPA in the National Climate Program are risk assessment and improvement of confidence in risk estimates. In addition to filling these roles in the research being undertaken within the National Climate Program (U. S. Department of Commerce, 1987), EPA has been asked by Congress to provide reports on potential effects of global climate changes and stabilization strategies. These reports to Congress are scheduled to be completed in the next year.

At least six major programs within EPA are being established to perform the work necessary for: (1) supporting the National Climate Program, (2) furthering the state of knowledge concerning climate processes and the effects of atmospheric pollutants on those processes, and (3) providing the analyses and assessments necessary for the reports to Congress.

Five readily identifiable EPA global climate programs are:

- Emission and Control Technology Studies,
- Atmospheric Chemistry and Meteorology,
- Ecological Effects,
- Monitoring of Sensitive Systems, and
- Integrated Assessment.

The first five of these major research areas are being undertaken by laboratories within the EPA's Office of Research and Development. While plans are being made in each of these areas for a longer-term research effort, information generated in the short term will be important in developing the reports to Congress. Thus, the EPA's Office of Research and Development, together with the EPA's Office of Policy Planning and Evaluation, will provide the reports to Congress.

This research plan covers the first two areas of research to be undertaken by EPA's Air and Energy Engineering Research Laboratory (AEERL). In assuming the responsibility for emission inventories and forecasting, AEERL will be developing the technical basis for assessment of emissions and emission changes for global climate research. Additionally, in investigating control technology and supporting control technology development, AEERL will be continuing its major role in solving air pollution problems. The AEERL's program designed to develop the necessary technical basis is composed of five major parts:

- emission inventory
- emission factor development
- emission forecast model
- control technology assessment
- control technology development

The AEERL's plan for accomplishing the necessary work in each of these areas is the subject of this 5-year research plan. It was prepared for discussion with senior scientists and program managers at the EPA's Global Climate Change Program Workshop, to be held in September 1987. The next section of this research plan, Section 2.0, shows conceptually how AEERL's work may complement and add to work done by other researchers and how their work might add to AEERL's work. Section 3.0 contains AEERL's basic research plan, complete with technical approach, budgets, and schedules for deliverables for the five program elements listed above. Section 4.0 is an assessment of the current state of knowledge and technical resources with respect to the goals of the research plan.

2.0 RELATION OF AEERL RESEARCH TO OTHER AREAS OF GLOBAL CLIMATE RESEARCH

Figure 1 shows an example of how information developed by AEERL may relate to research in other areas of global climate research. Global climate research is very complex, and the different research areas are highly interrelated having many complementary relationships. The figure is necessarily simplified to show some of the major components of AEERL's work.

2.1 RELATION TO ATMOSPHERIC CHEMISTRY RESEARCH

As shown in Figure 1, information from AEERL's work in inventorying and predicting emission rates will be available for use by atmospheric chemistry researchers. One group of these researchers resides within the EPA's Atmospheric Sciences Research Laboratory. It is anticipated that atmospheric chemistry researchers will use predictions of future emission rates to predict atmospheric concentrations of greenhouse gases.

The results of research in atmospheric chemistry of greenhouse gases also have implications for AEERL's work in emissions estimates and forecasts. For example, atmospheric concentrations of CO_2 are an important factor in estimating CO_2 emissions and uptake in the biota and, in that sense, represent an important feedback loop to the emissions estimation work. Other important feedback mechanisms, especially among natural sources, may also be identified.

2.2 RELATION TO GENERAL CIRCULATION RESEARCH

Information generated in the emission inventory and forecast activities may not be used directly by researchers in the general circulation modeling area. However, information generated by such researchers will be important for use in emission estimates and predictions. Many emission estimates are dependent on temperature and precipitation. For example, estimates of:

- emissions due to energy use for space heating and cooling;
- emissions from agriculture;
- emissions from natural sources; and
- changes in chlorofluorocarbon emissions due to changes in usage for insulation, air conditioning, and refrigeration.

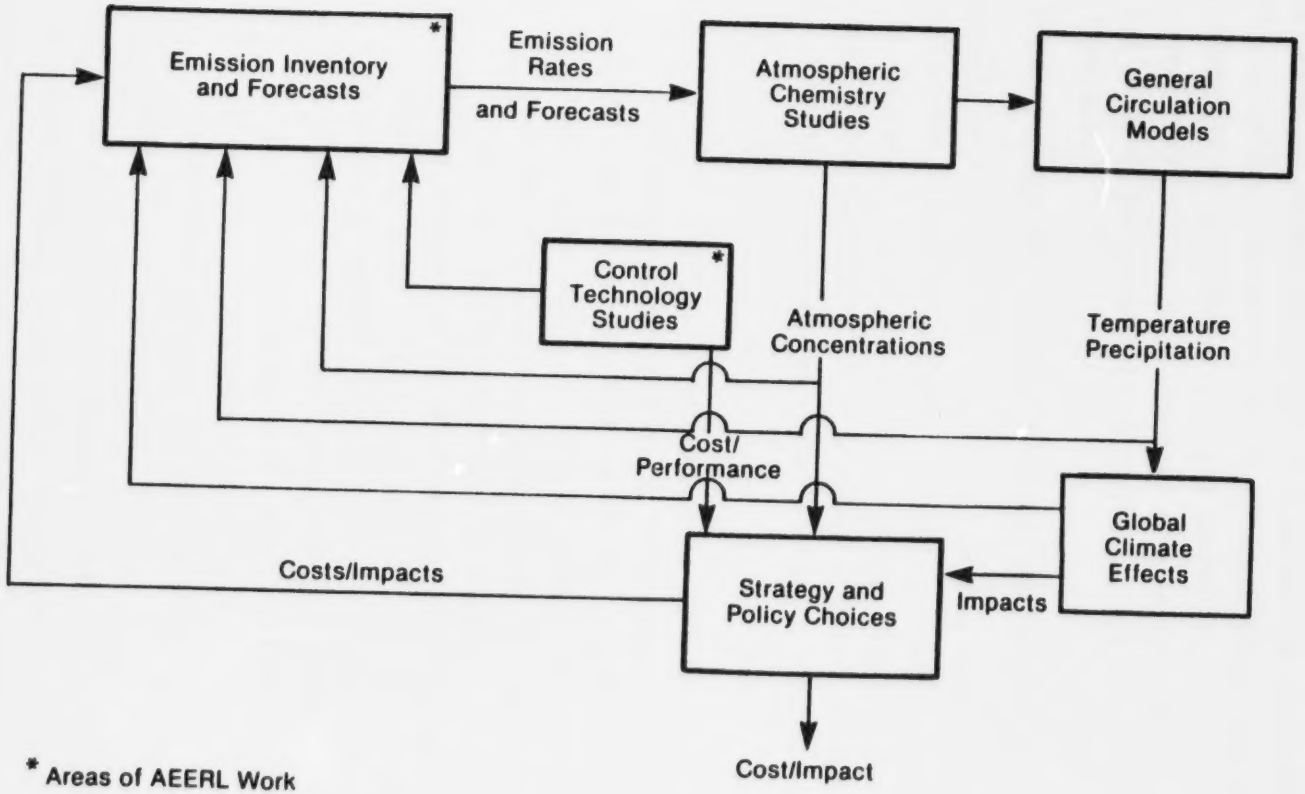

Figure 1. Relation of AEERL Research to Other Areas of Global Climate Research

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2.3 RELATION TO EFFECTS RESEARCH

Predictions of effects of climate changes will be important for forecasting emissions. As natural biota and agricultural areas shift, for example, locations of emission sources and quantities of emissions will also change. Thus, results from researchers working in the effects research area, such as the group of EPA scientists in Corvallis, will be valuable in refining emission forecasts.

2.4 RELATION TO STRATEGIES AND POLICY CHOICES ANALYSES

Especially important in the short term, for the reports to Congress, but also of continuing importance to global climate research, are the activities relating to strategies for changing or coping with climatic changes. Many of these strategies can be thought of in terms of scenarios or "what if?" questions. Examples of some of the policy actions or situations that might be simulated include:

- holding temperature increase to a certain level;
- holding emissions of a gas or from a source constant;
- holding atmospheric concentrations of a gas constant;
- reducing emissions of a gas or from a source;
- reducing atmospheric concentrations of a gas;
- decreasing regional emissions of a gas;
- implementation of different energy polices, such as imposing taxes on fossil fuels;
- population control strategies;
- changes in agricultural practices;
- regulatory penetration of U. S. chlorofluorocarbon, ozone, and criteria pollutant regulations;
- reforestation policies or their absence; and
- destruction of agricultural lands.

For each of these scenarios, information needed includes changes predicted in global climate, costs, and other economic impacts of actions simulated, and predicted changes in emissions and atmospheric concentrations.

Information generated by analysts working in this area will need to be exchanged rapidly with researchers in other areas of global climate research, so that effects of various scenarios can be predicted. The EPA's Office of Policy Planning and Evaluation will be working in this area, especially in the preparation of the reports to Congress.

Control technology assessment and development will be another important link between the emission inventory and forecast work and the strategy and policy choices analyses. To evaluate control strategies using control technology, information on control technology efficiency and effectiveness will be needed on a consistent basis. The results of applying control technology can then be reflected in emission forecasts. Costs of applying available control technology will be necessary to predict the impacts of controls on society.

Moreover, if a strategy for stabilizing climate is determined to be unattractive due to cost or technological factors, control technology may have to be developed to overcome such hurdles.

3.0 AEERL GLOBAL CLIMATE RESEARCH PLAN

This section contains the 5-year research plan for AEERL's global climate research programs. The AEERL's research plan has been designed to accommodate the needs of the National Climate Program and the reports to Congress and, at the same time, to produce information supporting a broad range of research activities in global climate. The AEERL's research is divided into five major programs:

(1) emission factor development,
(2) emission forecasting model,
(3) emission inventory,
(4) control technology assessment, and
(5) control technology development.

Figure 2 shows how these programs relate to each other. As the figure shows, the activities required in these programs are highly interdependent. Each of these programs is discussed in detail in the next portion of this section. Descriptions include objectives, technical approach, and deliverables for each program. Program budgets and schedules are presented at the end of this section.

3.1 EMISSION FACTOR DEVELOPMENT PROGRAM

3.1.1 Objective

The objective of the emission factor development program is the development of a set of emission factors for sources and sinks of greenhouse gases. These factors will be used in the emission inventory program and the emission forecasting model program. An initial set of emission factors will be developed for use in the assessment model system, and a more extensive set will be developed for the scientific model system.

3.1.2 Technical Approach

The priority for developing emission factors will concentrate initially on combustion sources and industrial sources. An initial list of combustion sources of greenhouse gas emissions is presented in Table 1. Agricultural

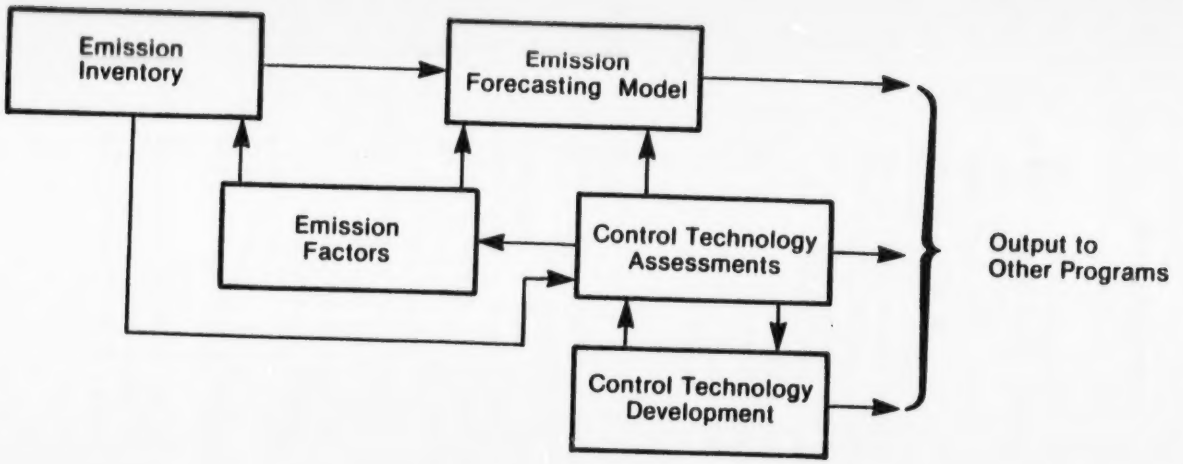

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Figure 2. Interrelationship of AEERL Programs

TABLE 1. COMBUSTION SOURCES OF GREENHOUSE GAS EMISSIONS

Major Categories	Subcategories
Utilities	Gas - boiler
	Gas - combined cycle
	Gas turbines
	Residual oil
	Distillate oil
	Shale oil
	Municipal waste - mass feed
	Municipal waste - refuse-derived fuel
	Coal - spreader stoker
	Coal - fluid bed - combined cycle
	Coal - fluid bed - boiler
	Coal - pulverized coal - cyclone
	Coal - pulverized coal - tangential
	Coal - wall fired
	Wood
Industrial Boilers	Wood
	Gas - low thermal efficiency
	Gas - high thermal efficiency
	Residual - low thermal efficiency
	Residual - high thermal efficiency
	Distillate - low thermal efficiency
	Distillate - high thermal efficiency
	Municipal waste
	Refuse-derived fuel
	Coal - fluid bed
	Coal - spreader stoker - low thermal efficiency
	Coal - spreader stoker - high thermal efficiency
	Coal - pulverized coal
	Coal - mass stoker
	Bagasse/agricultural waste
Fuel Production	Gas production & refining
	Oil production & refining - w/CH_4 wastage
	Oil production & refining - w/o CH_4 wastage

(continued)

TABLE 1 (CONTINUED). COMBUSTION SOURCES OF GREENHOUSE GAS EMISSIONS

Major Categories	Subcategories
Fuel Production (Concluded)	Coal production & cleaning Oil shale production & refining Coal gasification - current technology Coal gasification - advanced technology Coal liquefaction Charcoal production
Transportation	Rail Jet aircraft Ship Aviation gasoline Gasoline - light duty - pre-control Gasoline - light duty - post-control Gasoline - heavy duty Gasoline - light duty Diesel - light duty Diesel - heavy duty Methanol - light duty Methane - light duty Internal combustion engines - diesel } pipeline Internal combustion engines - gas } transportation Gas turbines
Residential/Commercial	Direct fired - wood pits wood fireplace wood stove - old/modern gas heater - old gas heater - modern (pulse) oil - old oil - modern coal fireplace coal stove coal central heat propane/butane

(continued)

TABLE 1 (CONCLUDED). COMBUSTION SOURCES OF GREENHOUSE GAS EMISSIONS

Major Categories	Subcategories	
Residential/Commercial (Concluded)	Boilers	- wood
		gas
		residual oil
		distillate oil
		municipal waste
		coal
		shale
	Waste reduction	- open burning - municipal waste
		open burning - agricultural
		incineration - low efficiency
		incineration - high efficiency
Heaters/Furnaces/ Kilns/Ovens/Dryers	High Temp	- distillate oil
		gas
		residual oil
		coal
		shale oil
	Intermediate Temp	- distillate oil
		gas
		residual oil
		coal
		shale oil
	Low Temp	- distillate oil
		gas
		residual oil
		coal
		shale oil

emission sources will be pursued next, followed by natural emission sources and emission sinks. The major categories of noncombustion sources and sinks are listed in Table 2.

The emission factor for each source category will represent the most common fuel and process used by the category. In addition to emission factor data, data will be collected on efficiency, cost, and availability of the source category technology and the emission controls that could be applied to the source category. These data will be compiled in the format of Table 3, "Combustion Emission Sources."

Initially, emission factor data will be collected from available documents developed by EPA, other Government agencies working on the National Global Climate Program, and the scientific community studying global climate issues. After the available data have been compiled and evaluated, data gaps will be identified and prioritized by potential contribution to global climate change. Testing activities will then be designed and implemented for developing emission factors for important source categories having no (or at least limited) data.

The testing activities include design of sampling and analytical strategies, preparation of testing plans, test site selection and preparation, execution of testing activities, analysis of emission samples, and conducting quality assurance/quality control audits. The test data will be used to refine initial emission factors and default assumptions, and to fill data gaps.

In considering the relationship of the emissions forecast model to other global climate research, it is important to consider methods for handling uncertainty in the data. Because the emission inventory and forecasting may be the foundation for many predictions of atmospheric concentrations and climate changes, uncertainty in the emissions estimates may be propagated throughout the estimates. It is unlikely that mathematical expressions of this uncertainty can be developed. Therefore, global climate researchers have requested that indications of data quality accompany the emission inventory and forecasting model results. Data quality indicators may be useful, not only for judging quality of model estimates, but also for

TABLE 2. NONCOMBUSTION SOURCES AND SINKS OF GREENHOUSE GAS EMISSIONS

Major Categories	Subcategories	Source/Sink
Industrial, Manuf.	Petrochem. producers	Source
Industrial, Manuf.	Metals processes	Source
Industrial, Manuf.	Mineral processes	Source
Industrial, Manuf.	Other	Source
Industrial	Fossil fuel prod.	Source
Industrial	Fire extinguishers	Source
Industrial	Solvent use	Source
Industrial	Refrigerants/AC	Source
Industrial	Foams	Source
Industrial	Propellants	Source
Industrial	Fumigants	Source
Industrial	Landfill & waste disp.	Source
Agricultural	Enteric (animals)	Source
Agricultural	Rice	Source, Sink
Agricultural	Other (fertilizer)	Source, Sink
Natural	Inland wetlands	Source, Sink
Natural	Coastal wetlands	Source, Sink
Natural	Soil (bacterial)	Source, Sink
Natural	Forests, deciduous	Source, Sink
Natural	Forests, coniferous	Source, Sink
Natural	Forests, tropical	Source, Sink
Natural	Other vegetation	Source, Sink
Natural	Volcanoes	Source
Natural	Lightning	Source
Natural	Oceans	Source, Sink
Natural	Ice caps, permafrost	Source, Sink

TABLE 3. COMBUSTION EMISSION SOURCES

Emission Source Technology	Efficiency (%)	Cost ($/joule)	Availability (date)	Emissions (kg/joule)					Applicable Control Technology Codes
				CO_2	CO	CH_4	N_2O	NO_x	
Categories include utility, industrial, residential/commercial, transportation.	Utility eff. = fuel heat value/ electricity delivered to user. Industrial and residential eff. = fuel energy in/ energy delivered to user. Note: Transportation efficiency is omitted.	Joule = energy delivered to user. Omit cost for residential and transportation. $ = cost in 1985 excluding fuel costs.	The year this technology is commercially available.	Joule = energy delivered to the user except transporation and heater/furnace/ kiln/oven/dryer where joule is fuel heating value. Emissions = uncontrolled emissions.					

directing sensitivity analyses. Therefore, each emission factor will be accompanied by a qualitative rating of its accuracy and its pedigree. The qualitative accuracy rating will consider the quantity and quality of the data used to develop the emission factor. The pedigree information will include the references, data bases, assumptions, and methodologies used to develop the emission factor.

3.1.3 Deliverables

Draft assessment model emission factors	12/87
Revision 1 emission factors data set	09/88
Testing strategy	03/89
Revision 2 emission factors data set	09/89
Initiate testing program	10/89
Revision 3 emission factors data set	09/90
Revision 4 emission factors data set	09/91
Revision 5 emission factors data set	09/92

3.2 EMISSION FORECASTING MODEL PROGRAM

3.2.1 Objective

The objective of the emission forecasting model program is the development of a computer model for the forecasting of global emissions of greenhouse gases into future years.

3.2.2 Technical Approach

The primary focus of this program is the development of a scientific computer model to forecast global emissions of greenhouse gases, taking into account more and more detail as work proceeds in the global climate area to generate that detail. In the shorter term, AEERL will also be providing support to an assessment modeling effort by policy analysts, such as the EPA's Office of Policy Planning and Evaluation in the work required for the reports to Congress. The concept is to allow policy analysts to begin generating results soon. Results will be refined as the work progresses and more detailed causes and effects can be incorporated. An assessment model is to be completed by the Office of Policy Planning and Evaluation and the

Office of Research and Development by December 1987. The major AEERL contribution to this effort will be an emission forecasting algorithm for noncombustion industrial sources of CO_2, CO, NO_x, N_2O, and methane. The emission forecasting model will be developed for the IBM 3090 computer at the EPA National Computer Center. Key features of the emission forecasting model are shown in Table 4. As listed in Table 4, the emission forecasting model for the scientific global climate model system will forecast emissions from all major natural and anthropogenic sources and sinks for approximately 15 greenhouse gases. The model will be capable of forecasting emissions out to the year 2000, as well as backward to the year 1700 to allow calibration with known global climate changes in the past. The spatial resolution of the model is expected to be on a 1^0 latitude by 1^0 longitude scale with elevation designations for NO_x emission species.

In addition to annual emission forecasts, the emission forecasting model will be capable of apportioning the annual emission forecasts to yield seasonal estimates. The forecasting model will also be capable of making forecasts under the constraint of emission control strategies. If control strategies are applied, the model will be capable of calculating the ecqnomic, energy, and secondary environmental impacts of applying the controls.

The scientific emission forecasting model will be built upon the forecasting techniques being developed now by the Agency for the assessment emission forecasting model. However, the scientific emission forecasting model, unlike the assessment emission forecasting model, will be capable of providing the more highly resolved emission forecasting data required by state-of-the-art climate models. The inputs to the forecasting routines will be activity factors such as labor productivity trends, population trends, and per-capita gross national product trends. Great care will be taken to coordinate the scientific emission forecasting model with the other models of both the scientific and assessment global climate systems to ensure that all inputs, outputs, and basics are mutually compatible.

3.2.3 Deliverables

Operational noncombustion anthropogenic module for assessment model	12/87
Scientific emission forecasting model specifications	09/88

TABLE 4. DESIRABLE FEATURES FOR EMISSION INVENTORY AND FORECASTING MODEL

Parameter	Assessment Model	Scientific Model
Domain	Natural and anthropogenic sources and sinks	Natural and anthropogenic sources and sinks
Gases (in order of importance)	CO_2 Halocarbons (CCl_4, methylchloroform, CFC-11, CFC-12, CFC-22, CFC-113, Halon 1211, Halon 1301) CH_4 N_2O CO NO VOC	CO_2 Halocarbons (CCl_4, methylchloroform, CFC-11, CFC-12, CFC-22, CFC-113, Halon 1211, Halon 1301) CH_4 N_2O CO NO SO_x Particulate matter
Time Horizon	1700-2200	1700-2200
Temporal Increments	1700-1975 25 yr. 1975-2000 5 yr. 2000-2100 10 yr. 2100-2200 25 yr.	1700-1975 25 yr. 1975-2000 5 yr. 2000-2100 10 yr. 2100-2200 25 yr.
Temporal Resolution	Annual average emission rates	Annual average emission rates with seasonal apportionment
Space	Global emissions resolved into nine major regions: U.S.A. Organization for Economic Co-operation & Development West Organization for Economic Co-operation & Development Asia Centrally Planned Europe Centrally Planned Asia Middle East Africa Latin America South and East Asia	1° lat. x 1° long. global grid with elevation for N_2O, NO_x, and lightning
Categories	Major categories	Major categories and subcategories

Prototype of scientific model emission forecast model	09/89
Initial operation of complete scientific global climate model system	09/90
Fully operational scientific global climate model system	09/91
Revision 1 of fully operational scientific global climate model system	09/92

3.3 EMISSION INVENTORY PROGRAM

3.3.1 Objective

The objective of the emission inventory program is the development of a comprehensive inventory of greenhouse gas emissions on a global scale. The inventory is to be available on an aggregated basis for the assessment global climate model system and on a highly resolved basis for the scientific global climate model system.

3.3.2 Technical Approach

A global inventory of existing sources and sinks of greenhouse gases will be developed using a three-phase approach:

(1) a summary inventory based on readily available data,
(2) an assessment inventory resolved into nine global regions, and
(3) a scientific inventory resolved to 1^0 latitude and longitude.

Although some portions of these work elements can proceed in parallel, these steps are largely incremental in nature, each step building on the previous step. The initial inventory will be a global summary based on readily available data. This initial inventory will then be refined through the collection of additional data and disaggregation of data to produce an inventory for the nine regions used in the assessment model system.

With subsequent revisions, the inventory will provide improved data with 1^0 resolution for use in the scientific model system. Where the data do not allow 1^0 resolution, disaggregation based on activity indicators or some similar surrogate may be necessary.

An integral part of the development of the inventory is the development of a data management system that will facilitate updating and documentation of data. The data management system will allow easy determination of how a

particular piece of data was generated (real records, estimated from population, estimated from GNP, etc.). The system will also include aggregation routines to produce less highly resolved inventories that are fully consistent with the input requirements of other computer models such as the assessment global climate model system.

Updates are planned for the emission inventory at 1-year intervals to reflect new and/or improved data which have resulted from the research plan. Inventory updates may also be required to respond to the needs of other global climate researchers.

3.3.3 Deliverables

Summary inventory	4/88
Initial assessment inventory	9/88
Scientific inventory and data management system	9/89
Revision 1 scientific inventory	9/90
Revision 2 scientific inventory	9/91
Revision 3 scientific inventory	9/92

3.4 CONTROL TECHNOLOGY ASSESSMENT PROGRAM

3.4.1 Objective

The objective of the control technology assessment program is to identify feasible control technologies and strategies which could be employed to stabilize the earth's climate. Control technology effectiveness, performance, cost, energy and environmental impacts, institutional barriers to commercialization and application, and expected penetration rates will be considered and put on a consistent basis for consideration of strategy development.

3.4.2 Technical Approach

The initial activity in this program will be to collect readily available control technology data similar to data collected for emission source categories. Initial control technology data will provide inputs to the assessment inventory and forecasting model currently under development by the Agency. Control techniques are not restricted to add-on equipment, but

include such measures as process changes and raw material and fuel substitution. Moreover, in view of the time-frame projection into the future, control techniques of interest from the control technology assessment point of view range from those currently available to those that may be available in the future; e.g., advanced fluidized bed combustors, magneto-hydrodynamics, fuel cells, and fusion. The ultimate aim will be a list of control options and potential control effectiveness for each global climate pollutant. The format for the initial control technology data is presented in Table 5, and will include control technologies both currently available and under development.

Subsequent activities of the control technology assessment program will shift focus toward the assessment of emerging technologies potentially applicable to the control of greenhouse gases. Scientific literature will be reviewed, and development projects in both the governmental and private sectors around the globe will be monitored to provide the necessary data. The results of these assessments will be key inputs into the emission forecasting model, control strategies and policy analyses, and the AEERL control technology development program (discussed next).

First, emerging technologies applicable to control of greenhouse gases will be investigated and prioritized. Those technologies that appear feasible from both engineering and economic viewpoints will be studied in more detail, tracked in future years, and considered for research and development efforts. Information to be developed for each control technology includes:

- reliability;
- cost;
- technical feasibility;
- commercial availability and timing;
- expected penetration rate; and
- impacts: environmental, energy, social, economic.

The result will be an assessment report presenting the relevant data on all applicable control options for each global climate pollutant. Technology assessment reports will be produced in September of each year, starting in 1989.

TABLE 5. EMISSION CONTROL TECHNOLOGIES

Control Technology	Device Code	Efficiency Penalty[a] (%)	Cost ($/joule)	Availability (date)	Performance (% reduction) CO_2	CO	CH_4	N_2O	NO_x
		Expressed as % of combustion device efficiency.	Cost = 1985 $. Joule = energy delivered to user.						

[a] May be a benefit in some cases.

Technical information developed in this program will also be provided in the formats required for easy and ready entry into the various computer models that depend on these inputs.

The control technology assessment program will provide important information on feasible control options to the policy and strategy development efforts of the global climate program. In addition, this element will have major input as to the research and development needs of the more promising technologies for the control technology development program.

3.4.3 Deliverables

Control technology summary table	04/88
First control technology assessment report	09/89
Second control technology assessment report	09/90
Third control technology assessment report	09/91
Fourth control technology assessment report	09/92

3.5 CONTROL TECHNOLOGY DEVELOPMENT PROGRAM

3.5.1 Objective

The objective of the control technology development program is to identify and support development of key potential control technologies for greenhouse gases as early as possible.

3.5.2 Technical Approach

Control technology development activities will arise from control technology assessment activities. They may also arise from consideration of an attractive stabilization strategy for which suitable control technology is not available. Moreover, if a strategy is determined to be unattractive due to cost or technological factors, control technology may need to be developed to overcome such hurdles. The goal will be to support development and commercialization of feasible and cost-effective control techniques necessary for implementation of attractive control strategies. A research and development plan will be written for each technology to be supported. This plan will analyze the perceived hurdles to commercialization and design the activities required to surmount these hurdles. The development plan will include technical approach, schedule, budget, peer review, and QA/QC controls.

Control technology development activities generally proceed in sequential steps:

- conceptual analysis;
- fundamental design;
- laboratory and bench-scale testing;
- pilot-scale/prototype testing;
- full-scale demonstration; and
- commercialization.

This evolutionary process starts with many concepts being initially evaluated, a few being tested at pilot scale, and perhaps one or two being commercialized. This "survival of the fittest" approach ensures that only the most cost-effective techniques with the highest probability of success receive significant funding. The first research and development plan will be provided in October 1989 with progress reports and development plan revisions annually thereafter.

Any advance in control technology will be reflected in the control technology assessment reports which will also be integrated into the emission forecast model. Thus, the emission forecast model and the control strategy/policy choices model will always be able to reflect the latest control technology information in their analyses.

3.5.3 Deliverables

Research and development plan	10/89
First progress report and revised R&D plan	10/90
Second progress report and revised R&D plan	10/91
Third progress report and revised R&D plan	10/92

3.6 SCHEDULE

The 5-year AEERL Research Plan schedule is summarized in Figure 3. Details about each of these program deliverables have been discussed previously.

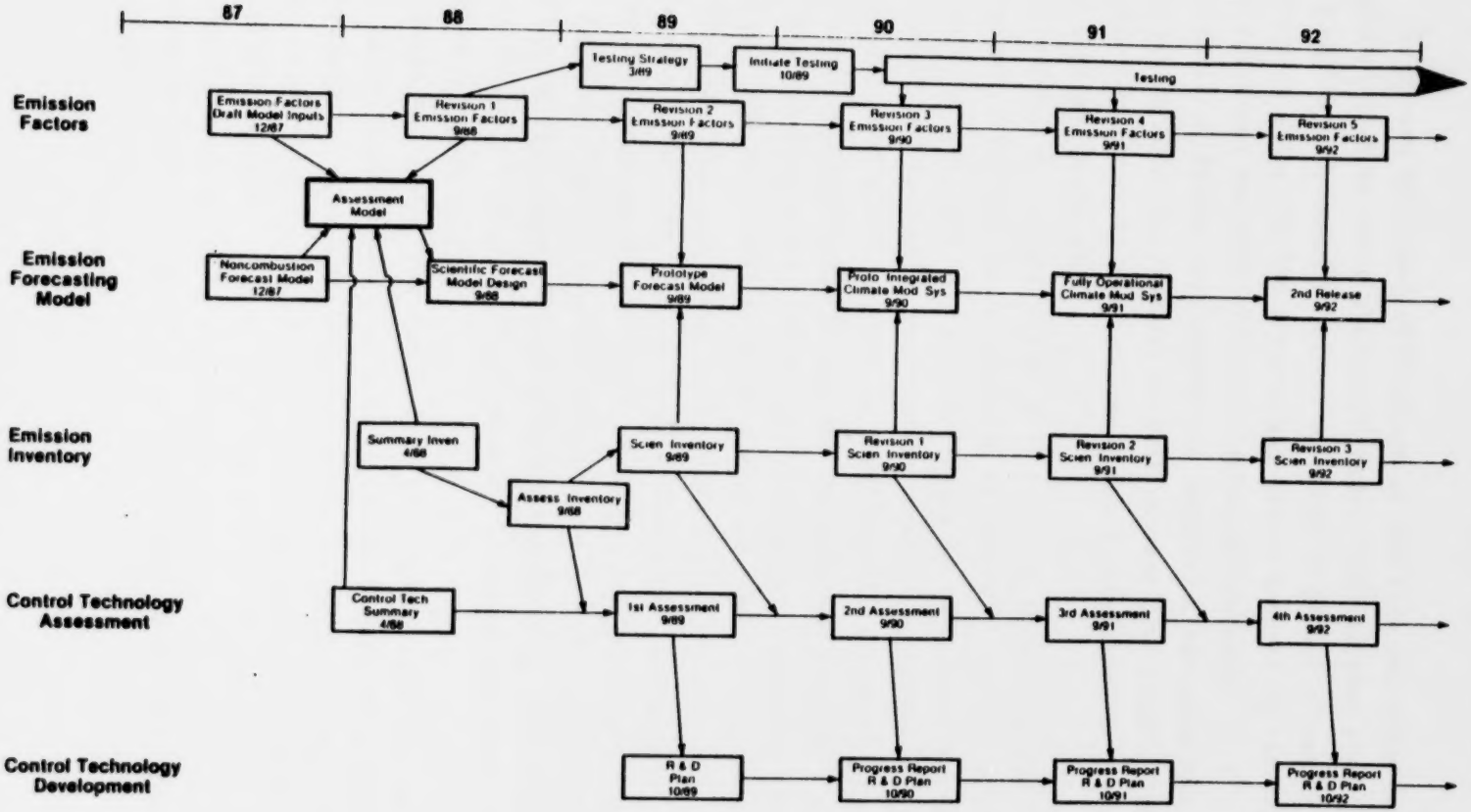

Figure 3. AEERL Global Climate Change 5-Year Research Plan

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To ensure efficient utilization of the time and money available, it is important that no false starts are made. This program plan will be presented at a workshop designed to enlist opinions of global climate researchers concerning plans for the program and advice concerning the highest quality data resources and most effective technical approach.

Emission factor development and industrial noncombustion emission forecasting model development activities have just begun. These activities provide key inputs to the assessment model scheduled for prototyping in late 1987 and early 1988.

Emission factor activities will continue throughout the 5-year program. Subsequent revisions to the emission factors will include additional and more accurate factors, and will provide inputs to subsequent versions of both the assessment and scientific emission inventory/forecasting models. In areas where emission factor accuracy is insufficient, a testing program will be initiated in October 1989 to upgrade the emission factors.

The modeling activities begun this year will continue throughout the program. The assessment model initiated in 1987 will continue to be a valuable strategy assessment tool and will be maintained and upgraded on a continuing basis. In 1988, work will also begin on the development of a scientific model which will reach prototype demonstration stage in 1990.

Emission inventorying activities begin in 1988 and continue through the program. A key element of the emission inventorying activities is the initiation of a highly resolved emission inventory and associated data base management system in 1989.

Based on inputs from the initial emission inventories and assessment model results, assessments will be initiated in 1989 on potential control technologies for the most important global climate problem areas. These control technology assessments will continue through the program as new technologies emerge. Outputs from the control technology assessments provide performance information to the control strategy and policy choice analysts and important decision material to the control technology research and development plan.

The first control technology development plan will be prepared in 1989. This plan will provide for enhancing the development and commercialization of control technologies which are important to the stabilization of the global climate change. The research and development plan will be reviewed and updated annually to reflect the results of subsequent global climate modeling, subsequent control technology assessments, and findings of the control technology research and development program to date.

3.7 RESOURCE REQUIREMENTS

The resource requirements for the AEERL Research Plan are presented in Table 6. The resources presented for 1987 reflect actual resource allotment. These resource requirements are divided by the five program elements discussed above and are presented by fiscal year (October 1 through September 30).

TABLE 6. RESOURCE REQUIREMENTS FOR AEERL'S RESEARCH PLAN FOR THE GLOBAL CLIMATE EMISSION ASSESSMENT AND STABILIZATION PROGRAM ($)

	1987	1988	1989	1990	1991	1992
Emission Inventory	25,000	200,000	650,000	250,000	250,000	250,000
Emission Factor Development	100,000	150,000	250,000	2,000,000	2,000,000	2,000,000
Emission Forecast Model	50,000	150,000	500,000	500,000	500,000	500,000
Control Technology Assessment	25,000	50,000	100,000	100,000	100,000	100,000
Control Technology Development	----	----	----	1,000,000	2,000,000	3,000,000
Total	200,000	550,000	1,500,000	3,850,000	4,850,000	5,850,000

4.0 CURRENT STATUS: AVAILABLE MODELS AND DATA BASES TO SUPPORT THE GLOBAL CLIMATE ASSESSMENT AND STABILIZATION PROGRAMS

The previous section identified the desirable endpoints of AEERL's program in global climate. This section will assess the current status of information and research to support the work needed to reach those endpoints.

4.1 EXISTING DATA AND MODELS FOR EMISSION INVENTORY AND FORECASTING

4.1.1 Emission Data

In general, emission estimates are derived from direct estimates or from the following type of expression:

(emission estimate) = (emission factor) x (activity indicator).

For example,

$$(\text{kg } NO_x/\text{yr from coal combustion}) = \frac{(\text{kg } NO_x)}{\text{Mg coal combusted}} \times (\text{Mg coal combusted/yr}).$$

Much work has been done to develop emission factors for anthropogenic sources in the United States and a few other industrialized nations. However, for third world countries and for natural sources, very sparse emission data are available. Even so, a consistent data base is required, utilizing standard emission factors and activity levels for the entire globe.

Emission factors for each gas and for each major emission source are required input to the emission forecast model. These emission factors must be in consistent units of amount of gas released per unit of activity (i.e., per amount of fuel burned, or per acre of land cleared).

Table 7 summarizes existing studies which include emission data for the major source categories and gases. High quality emission data bases are available for combustion sources for industrialized nations, while less data are available for some important emission sources in third world countries. For example, residential burning of wood fuel in developing countries, resulting in substantial CO emissions, is an important source category for which very little emission data are available. Emission factors for this

TABLE 7. SOURCES OF EXISTING EMISSION DATA FOR MAJOR CATEGORIES AND GASES OF INTEREST TO GLOBAL CLIMATE MODELING

Source Category	CO, NO_x	Halocarbons	CH_4	VOC	CO_2	N_2O
Combustion	o U.S. and Canada - NAPAP Emis. Inv. o China - World Bank o 3rd World - Resource for Future Study o Edmond's Model o Europe - Acid Dep. Studies	-	o World Met. Org.	o U.S. and Canada - NAPAP Emis. Inv. o Europe - Acid Dep.	o Edmond's Model o NAS Study o DOE Study	-
Transportation	o U.S. - EPA, DOE o USSR - NATO, CIA o China - World Bank o International Energy Agency o Exxon Study o Edmond's Model	-	o World Met. Org.	o U.S. - EPA, DOE	o Edmond's Model o NAS Study o DOE Study	-
Industrial	o U.S. and Canada - NAPAP Emis. Inv. o USSR - NATO, CIA o China - World Bank o Europe - Acid Dep. Studies	o U.S. - EPA/RIA Study o Chem. Manf. Assoc. o UNEP Internat. Chlorofluorocarbon Meeting Proc.	o World Met. Org.	o U.S. and Canada - NAPAP Emis. Inv. o Europe - Acid Dep. Studies		-
Agricultural	o 3rd World - World Resources Report o U.S. - Food & Ag.	-	o Rassmussen and Khalil (Oregon Graduate Center) o World Met. Org.	-	o World Met. Org. o U.S. - Food & Ag.	o McElroy and Wofsey (Harvard)
Natural	o Global - Elaine Matthews (NASA) o World Met. Org.	-	o Global - Elaine Matthews (NASA) o Rassmussen and Khalil (Oregon Graduate Center) o World Met. Org.	o Global - Elaine Matthews (NASA)	o Global - Elaine Matthews (NASA)	o McElroy and Wofsey (Harvard)

category, and others that are not well characterized, may have to be estimated based on limited existing data, and extrapolated across broad geographic regions.

Agricultural and natural sources of methane, CO_2, and VOC are important source categories for which limited emission data are available globally. Data bases prepared by NASA include vegetation type and land-use for the entire globe on a 1^0 latitude by 1^0 longitude resolution (Matthews, 1986). The data bases have been designed to allow for flexibility in spatial aggregation to coarser resolutions, and for flexibility which allows users to aggregate vegetation types into broader groups. Natural and agricultural emissions of methane, CO_2, and VOC are key data needs for the emission inventory task.

A summary of source categories where emissions data are believed to be available is presented in Table 8. This table identifies where emissions data are available for the entire globe, for industrialized countries only, or for developing countries only.

Data quality varies widely in the existing emission data. Some of the data are based on actual emission tests, while others are best estimates based on very little "real" data. Most of the available data were generated for purposes other than developing a global greenhouse gas inventory. Consequently, it is expected that these data will have quality limitations. The identification of these data quality limitations must be an early activity of future emission inventory programs.

4.1.2 Population and Economic Data

Forecast factors required for the forecast model include population estimates, labor productivity, and economic factors such as GNP or GNP per capita. Nathen Keyfitz from Harvard University has published numerous papers estimating population growth and population shifts into the future. Several linear programs which estimate future fuel use, associated costs, and economic scenarios are also available.

TABLE 8. SUMMARY OF EMISSION DATA BELIEVED TO BE AVAILABLE THROUGH PRELIMINARY LITERATURE SEARCH

Major Categories	Subcategories	Species of Interest						
		CO_2	CH_4	N_2O	CO	NO_x	VOC	Halocarbons
Combustion	Utility, coal	I	-	I	I	I	I	-
Combustion	Utility, oil	I	-	I	I	I	I	-
Combustion	Utility, gas	I	-	-	I	I	I	-
Combustion	Utility, NFF	I	-	-	I	I	I	-
Combustion	Res./Comm., coal	I	-	I	I	I	I	-
Combustion	Res./Comm., oil	I	-	I	I	I	I	-
Combustion	Res./Comm., gas	I	-	-	I	I	I	-
Combustion	Res./Comm., nonfossil fuel	I	-	-	I	I	I	-
Combustion	Industrial, coal	I	-	I	I	I	I	-
Combustion	Industrial, oil	I	-	I	I	I	I	-
Combustion	Industrial, gas	I	-	-	I	I	I	-
Combustion	Industrial, NFF	I	-	-	I	I	I	-
Combustion	Agric. (non-energy)	X	X	-	X	X	X	-
Combustion	Clearing (non-energy)	X	X	-	X	X	X	-
Combustion	Wildfires (non-energy)	X	X	X	X	X	X	-
Combustion, Mobile	Cars, gasoline	G	X	G	G	G	I	-
Combustion, Mobile	Trucks, gasoline	G	X	G	G	G	I	-
Combustion, Mobile	Cars, diesel	G	X	-	G	G	I	-
Combustion, Mobile	Trucks, diesel	G	X	-	G	G	I	-
Combustion, Mobile	Other, diesel	G	X	-	G	G	I	-
Combustion, Mobile	Jets	G	X	-	G	G	I	-
Industrial, Manf.	Petrochem. producers	-	X	-	I	I	I	-
Industrial, Manf.	Metals processes	-	-	-	I	-	I	-
Industrial, Manf.	Mineral processes	I	X	-	-	-	I	-
Industrial, Manf.	Halocarbon production	-	-	-	-	-	I	G
Industrial, Manf.	Other	-	-	-	-	-	I	G
Industrial	Fossil fuel production	-	X	-	I	-	I	-

(continued)

TABLE 8 (CONCLUDED). SUMMARY OF EMISSION DATA BELIEVED TO BE AVAILABLE THROUGH PRELIMINARY LITERATURE SEARCH

Major Categories	Subcategories	Species of Interest						
		CO_2	CH_4	N_2O	CO	NO_x	VOC	Halocarbons
Industrial	Fire extinguishers	-	-	-	-	-	-	G
Industrial	Solvent use	-	-	-	-	-	I	G
Industrial	Refrigerants/AC	-	-	-	-	-	-	G
Industrial	Foams	-	-	-	-	-	I	G
Industrial	Propellants	-	-	-	-	-	I	G
Industrial	Fumigants	-	-	-	-	-	-	G
Industrial	Chlorofluorocarbon use, other	-	-	-	-	-	-	G
Industrial	Landfill & waste disposal	I	I	-	-	-	-	-
Agricultural	Enteric (animals)	-	X	-	-	-	-	-
Agricultural	Rice	-	G	-	-	-	-	-
Agricultural	Other (fertilizer)	-	-	G	-	X	-	-
Natural	Inland wetlands	G	G	G	-	X	-	-
Natural	Coastal wetlands	G	G	G	-	X	-	-
Natural	Soil (bacterial)	X	X	G	X	X	X	-
Natural	Forests, deciduous	G	-	G	-	X	X	-
Natural	Forests, coniferous	G	-	G	-	X	X	-
Natural	Forests, tropical	G	-	G	-	X	X	-
Natural	Other vegetation	X	G	G	X	X	-	-
Natural	Volcanoes	X	X	-	-	-	-	-
Natural	Lightning	-	-	-	-	X	-	-
Natural	Oceans	X	X	X	X	-	-	-
Natural	Ice caps, permafrost	X	-	-	-	-	-	-

KEY: G = Data may be available for entire globe.

I = Data may be available for industrialized countries only.

X = Data have not been identified.

- = Not considered a major emitter of pollutant.

4.1.3 Forecast Models

Emission forecasts are generally derived from the following types of expressions:

(emission forecast) = (forecast factor) x (base emission estimate) x

(emission factor) x (activity indicator)

For example,

$$\frac{\text{kg CO}}{\text{yr 2000}} = \frac{(\text{GNP})_{2000}}{(\text{GNP})_{1987}} \times \frac{\text{kg CO}}{\text{Mg coal combusted}} \times \frac{\text{Mg coal combusted}}{\text{year 1987}}$$

4.1.3.1 Energy Use Models. While many economic models estimate energy use for a given region, especially the United States, there are only a few global energy models. Most of these models are based on trend extrapolation, which may result in emission scenarios that are inconsistent with underlying, long-term, demographic, economic and regulatory forces. The two leading global energy models in use today are the Institute for Energy Analysis/Oak Ridge Associated Universities' (IEA/ORAU) Long-Term Global Energy Model developed by Edmonds and Reilly, and the Nordhaus-Yohe model developed by the National Academy of Sciences. The IEA/ORAU model is well documented and tested and was revised in 1984. Table 9 presents a comparison of the PC version of the IEA/ORAU model with the Nordhaus-Yohe model (Kavanaugh, 1987). The IEA/ORAU model results are the more disaggregate in terms of geographic regions and fuel types. This is an important feature because emissions per unit of energy may vary by an order of magnitude or more among fuels and end uses.

The IEA/ORAU model uses a multi-regional, equilibrium approach to estimate energy use (Edmonds and Reilly, 1986). The estimates are obtained by balancing regional demands for energy with regional and world supplies. Edmonds and Reilly originally designed the model to estimate future CO_2 emissions based on energy use forecasts. Kavanaugh later used the model to estimate CO and N_2O emissions from combustion sources (Kavanaugh, 1986). In Kavanaugh's work, model output was aggregrated into five fuel types and six geographic regions due to limitations in available input data.

TABLE 9. COMPARISON OF THE PC-VERSION IEA/ORAU ENERGY USE MODEL AND THE NORDHAUS-YOHE ENERGY USE MODEL

	IEA/ORAU	Nordhaus-Yohe
Geographic Regions	9	1
Fuel types	9	1
Sectors: Developed nations	4	1
Developing nations	1	1
User flexibility	Vary 12 parameters	0
Use by outside users	Yes	Not yet
Monte Carlo simulation for uncertainty estimates	Yes	Yes
Graphics	Yes	Limited

Source: Kavanaugh, 1987.

4.1.3.2 Halocarbon Forecast Models. Methods of projecting future demand for halocarbons take two approaches: (1) a "bottom up" approach; and (2) a "top down" approach. The bottom up approach relies on detailed specifications of all products that use species of halocarbons (such as aerosols, foams, air conditioners, and refrigerators). The future demand for each product is estimated based on such factors as population growth, economic growth, government regulation, and technological change. The projection of future halocarbon demand is compiled by adding the estimates of demand in each product, for each halocarbon species.

The top down approach does not rely on detailed specifications of the products, but instead employs an aggregate relationship between halocarbon use and general descriptions of overall demand for goods and services. Halocarbon use is related to overall economic activity (such as GNP or GNP per capita). Historical data and statistical methods are used to specify these relationships.

The bottom up approach is very data intensive, tends to be limited to existing products using halocarbons, and is most effective over short time periods (10 to 15 years). The top down approach is much less data intensive and can be applied more easily to make projections over a longer time period. Based on these factors, EPA selected a combination of the two methods as most useful for estimating future halocarbon demand.

Three halocarbon forecasting models which include a combined modeling approach were described by Kavanaugh in a working group meeting held at Radian Corporation in March 1987 (Kavanaugh, 1987). Comparisons of the Nordhaus-Yohe model, the ICF model, and the Rand model are summarized in Table 10. Additionally, a halocarbon forecasting model needs to go one step further than these existing models. The final output of the existing models is an estimate of future halocarbon demand. An algorithm needs to be developed relating halocarbon demand to halocarbon emissions. Emission rates from different end uses vary; for example, some applications emit halocarbons immediately (aerosol propellants, solvents), while others store halocarbons for long periods of time (refrigeration, air conditioning). Therefore, an end use allocation of production is required for each geographic region. Then emission rates for the various end uses can be assigned.

TABLE 10. COMPARISON OF THREE HALOCARBON FORECAST MODELS

	Nordhaus-Yohe	ICF	Rand
Halocarbon species included	11, 12	11, 12, 22, 113	11, 12, 22, 113
Products included	- Aerosol - Nonaerosol	- Aerosol - Nonaerosol - Some special studies	- Aerosol - Foams - Solvents - Others
Geographic regions	- Developed - Planned	- Developed - Developing - Planned	8 regions
Approach	- Monte Carlo Logistic	Economic	Economic
Policy implications included	Yes	Yes	Yes

4.1.3.3 Agricultural and Natural Emission Forecast Models. The Iowa Model was identified for forecasting agricultural demand and acreage. This model might be modified to forecast crop and fertilizer emissions. A model for forecasting emissions from natural sources was not identified from a review of the literature. Modeling capabilities must be developed for estimating emissions from this source. Input data on existing land use including acreage for natural areas and agricultural areas are available at 1^{o} latitude by 1^{o} longitude resolution (Matthews, 1986). Changes in these acreage figures over time can be estimated as a function of population growth, and economic and environmental factors. Algorithms need to be developed relating changes in land use to changes in these factors. Different relationships for industrialized countries and nonindustrialized countries also need to be developed. Emission coefficients for various land uses and natural sources exist in the literature.

4.2 EXISTING DATA IN CONTROL TECHNOLOGY ASSESSMENT AND DEVELOPMENT

Only limited work has been done in the area of controlling pollutants on a global basis as shown in Table 11. Control technology assessment and development work in the U. S. has been more regional or national in its perspective. For most of the greenhouse gas pollutants, control technology and development on a global scale will mean starting at the beginning.

TABLE 11. PRELIMINARY SUMMARY OF STATUS OF GREENHOUSE GAS POLLUTANT CONTROL TECHNOLOGY

	Control Techniques	Global Assessment	Global Information	U. S. Information
CO_2	Yes/DOE	Yes/DOE	Some	Yes
Chloro-fluorocarbons	Yes/EPA	Yes/EPA	Some	Yes
CH_4	No	No	No	No
N_2O	No	No	No	No
CO	Yes/EPA	No	Limited Europe & Japan	Yes
NO_x	Yes/EPA DOE	No	Limited Europe & Japan	Yes
VOC	Yes/EPA	No	No	Some

5.0 REFERENCES

U. S. Department of Commerce, National Oceanic and Atmospheric Administration. National Climate Program 5-Year Plan. Unpublished. July 1987.

Edmonds, J. A. and J. M. Reilly. The IEA/ORAU Long-term Global Energy-CO_2 Model: Personal Computer Version A84PC. Institute for Energy Analysis, Oak Ridge Associated Universities. ORNL/CDIC-16. December 1986.

Kavanaugh, M. "Estimates of Future CO, N_2O, and NO_x Emissions from Energy Combustion." Atmospheric Environment, Vol. 21, No. 3, pp. 463-468. 1987.

Kavanaugh, M. Memorandum to Radian Corporation regarding forecasting models. March 11, 1987.

Matthews, Elaine. "Data Needs and Data Bases for Climate Studies." Proc. ISLSCP Conf., Rome, Italy. December 2-6, 1985. ESA SP-248. May 1986.

APPENDIX A

OTHER AGENCIES WORKING IN THE AREA OF GLOBAL CLIMATE*

The EPA's work in the area of global climate change is developing in the context of other activities on the national and international level. The National Climate Program is closely aligned with the World Climate Program, and many U. S. government agencies, including EPA, have roles to play. Some of the major activities are summarized below.

The National Oceanic and Atmospheric Administration (NOAA) - NOAA performs research on weather and climate, makes forecasts, and issues warnings. It is the lead agency for the National Climate Program with major responsibility for the Climate Data and Services portion. Within the Research and Development portion of the National Climate Program, NOAA has responsibility for:

- long range climate predictions;
- development of a program to measure radiatively important trace gas concentrations in the atmosphere and oceans and to understand their interactions;
- studies of the response of the ocean to atmospheric forcing and the feedback systems involved with the maintenance and evolution of anomalous oceanic and atmospheric conditions.

The National Aeronautics and Space Administration (NASA) - NASA monitors atmospheric chemistry and models climate trends. NASA's activities within the National Climate Program include:

- a program to study the radiative effects of the changing atmospheric composition on climate;
- provision of a satellite observing system to include high accuracy altimeter measurements of sea surface elevation and measurements for surface stress;
- continuation of studies of radiation budgets and the effects of clouds, aerosols, and trace gases;

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*Some of this information was taken from an unpublished National Climate Program Plan (U. S. Department of Commerce, 1987). It may change as plans are finalized.

- continuation of research in the area of land-surface processes;

- planning for a tropical rainfall measuring satellite.

The Environmental Protection Agency (EPA) - EPA is the lead agency for the Interagency Coordinating Committee on Stratospheric Ozone Protection's work related to global climate change because the chlorofluorocarbon gases of concern are also greenhouse gases. On another front, EPA has been asked by Congress for reports in the areas of risk assessment and impacts analysis for global climate. Within the National Climate Program, EPA's part includes:

- assessment of the existing knowledge of the impact of climatic change on natural and managed ecosystems, taking into account socio-economic aspects;

- coordination of comprehensive regional assessments for one or more climatologically sensitive regions, taking into account possible impacts of climatic change, including short- and long-term socio-economical adjustments.

The Department of Energy (DOE) - DOE performs research in the area of the effects of CO_2 on global warming. Within the National Climate Program, DOE has the following role:

- assessment of the likely effects of limiting the growth of atmospheric concentrations of greenhouse gases, taking into account the full spectrum of socio-economic policy choices and closely related environmental problems of acidification of soils and lakes and depletion of stratospheric ozone;

- support of development of climate scenarios which provide regionally and seasonally specified simulations of a range of possible climate conditions suitable for assessing the effect of climatic changes on natural and managed ecosystems;

- evaluation of the collective effect of increasing levels of greenhouse gases on climate through a vigorous program of monitoring and modeling and identification of measures to control the rates of greenhouse gases increase by understanding the natural and anthropogenic sources and sinks for these gases.

The National Science Foundation (NSF) - NSF performs basic research on weather and climate dynamics. NSF also heads the Global Geosciences Program. NSF's role in the National Climate Program includes:

- continued support of research into the predictability of the coupled ocean/atmosphere system and its impact on the global climate;

- support of climate modeling research aimed at more accurately treating the interface between atmospheric and oceanic components of the climate system;

- support of research related to an improved understanding and modeling of the physical processes which influence atmospheric circulation in the polar regions, and observational studies related to parameterization of sea ice processes;

- coordination of a program of Arctic Climate Studies;

- support of research to obtain more complete data sets for periods which can be used as future climate analogs;

- support of research to examine the cause of fluctuations in past climates, to establish criteria for detecting long-term climatic change, and to develop statistically rigorous methods to distinguish between likely causes of climatic changes;

- support of the development of climate scenarios which provide regionally and seasonally specified simulations of a range of possible climate conditions suitable for assessing the effect of climatic change on natural and managed ecosystems.

This partial list of activities shows that there is opportunity for cooperation. Much of the information being developed will enhance the current data available for emissions inventorying and forecasting. For example, data on CO_2 generation and atmospheric concentrations developed by DOE will be valuable in completing a comprehensive inventory. Likewise, land use and CH_4 generation data being developed by NASA will be very helpful in developing forecasts. EPA's plans are designed to use all of the information generated by other agencies and researchers, building on previous and ongoing work. EPA's work is, in turn, expected to provide available emissions data in one central, easily accessible system for use by other agencies working in the global climate area.